Comparison of Several Eco-friendly Refrigeration Technologies[1]

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Abstract: In this paper, the operation principles, thermodynamics characteristics, and technical practicability were compared between thermoelectric refrigeration, magnetic refrigeration and adsorption refrigeration. The TE refrigeration is the most well-developed, applicable and competitive technology. Three eco-friendly refrigeration systems are increasingly getting attention, especially in a day with increasingly energy and environmental crises. In summary, thermoelectric refrigeration possesses the following superiorities: a longer developmental period, more perfect techniques, increasing applications, a larger range of refrigerating capacity, and a better economic property in small refrigerating capacity. Thermoelectric refrigeration cannot be replaced in special fields, and its applications have received more and more attention in recovering waste heat. Magnetic refrigeration has been widely applied in lower temperature regions; its application in middle temperature regions is juvenile. In particular, there is no application of this technique in high temperature regions. Adsorption refrigeration is practical only in near room temperatures. Its advantage is that it can be used in some fields where conventional refrigeration cannot be applied, such as in the application of solar energy, geothermal energy, and other renewable energy, and the recovery of residual and waste heat. Supported by the Young Foundation of Central South University of Forestry & Technology (06002A)

The disadvantages are as follows: the cost is expensive, no practical technique is available at present, and thus, it possesses no general superiority versus other refrigeration technologies.

Key words: operation principle; thermodynamics characteristic; technical practicability; thermoelectric refrigeration; magnetic refrigeration; adsorption refrigeration

1. INTRODUCTION

Refrigeration applications at the domestic, commercial and industrial levels are becoming an integral part of the present day living. The demand and supply of refrigeration systems is increasing day by day with the changing lifestyle. The existing compressor-based refrigeration (i.e., mechanical refrigeration) system has reached the maximum level of innovation. For the last few decades, there has not been any significant increase in the efficiency (i.e., COP) of the system. Moreover, with the increasing awareness of environmental degradation, the production, use and disposal of CFCs and HCFCs as refrigerants in mechanical refrigeration system has become a subject of great concern. However, such systems are being developed using more eco-friendly refrigerants viz., air, CO_2, NH_3, etc. Besides, efforts are being directed to develop other types of refrigeration technologies e.g., adsorption refrigeration, magnetic refrigeration and thermoelectric refrigeration which will be more eco-friendly, cost effective, efficient, simple in design, convenient and reliable.

2. ADSORPTION REFRIGERATION TECHNOLOGY

Adsorption refrigeration is especially applicable for the application of renewable energy, such as solar energy and geothermy, and the recycle of surplus or waste heat, which is one of the main advantages over mechanical refrigeration.

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2.1 Mechanism of Adsorption Refrigeration

The mechanism of adsorption refrigeration is shown in Fig 1. The adsorption system is sealed, when adsorbent filled in adsorber is heated, adsorbate adsorbed in adsorbent gains energy. When molecule movement rate of adsorbate is enough to overcome affinity between adsorbate and adsorbent, adsorbate will be desorbed. When sub-pressure of the system gradually increasing reaches the value of saturation steam pressure corresponding to environmental temperature, adsorbate desorbed from adsorbent will be liquefied. Heat discharged by liquefaction passes through condenser 2 and exchanges heat with refrigerant (such as air or water). When stop heating, adsorbent becomes cool, its adsorbing capacity gradually enhances again. At this moment, it adsorb refrigerating steam produced from evaporator 3, a vacuum state will be produced within refrigeration system, leading to the boiloff of liquid refrigerant. When refrigerant is evaporated, it absorbs heat, and thus system obtains the aim of refrigeration. Absorbent absorbing large quantity of adsorbate can be desorbed by heating. Adsorption-desorption cycles carry out go round and round, refrigeration process is conducted intermittently.

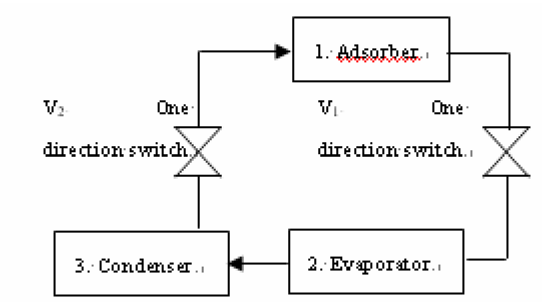

Fig. 1 Principle of adsorption refrigeration

The common lnp-T-1 connection of common theory cycle of adsorption refrigeration is presented in Fig. 2 [1]. It must be supplemented that bf and ea processes only schematically describes processes of condensation and evaporation refrigeration. In fact, both processes are isothermal which are described by broken line. The major difference between adsorption and compression refrigeration is that the adsorption-desorption of adsorption bed takes the place of inspiration and exhaust of comperssor.

2.2 The Development of Adsorbing Refrigeration Technology

The further development in adsorption refrigeration began in 1970's, adsorption refrigeration was first applied in solar energy field because of global energy sources crisis[2]. After 1990's, adsorption refrigeration was developed rapidly, and have been widely utilized in many fields including

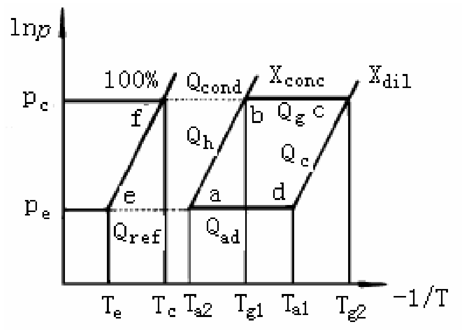

Fig.2 Common theory cycle of adsorption refrigeration

refrigeration of air-condition of industrial and civilian buildings, food, and industrial production, etc[3]. In addition, it is gradually applied in refrigeration of shipping[4], auto air-condition[5], etc.

At present, many studies about adsorption refrigeration are conducted in experiment equipment or sample, efforts must be paid to its practical application. Main investigations are contained as follows:

1) The study of adsorption medium pairs

Now, major work medium pairs include zeolite-water[6], actived carbon-methanol[7], actived carbon-ammonia[8], silica gel-water[9], chloride of alkaline earth metal-ammonia[10], and so on.

2) The investigation on refrigeration cycle manners and thermal-kinetics

The investigation in thermal-kinetics mainly focuses on the improvement of refrigeration manners which contain grade couplet and thermal wave cycles[11,12].

3) The study of adsorption bed

The key of application of adsorption refrigeration is an improvement in exchange velocity of heat and mass. The Adsorption beds being widely used at present include tube hull type peace plank type[13], still have the plank wings type in addition[14],spiral plank type[15],the wings slice tube type[16] and the heat tube type[17].

4) The analysis of economical characteristic of adsorption refrigeration system[18]

3. MAGNETISM REFRIGERATION TECHNOLOGY

As a green refrigeration technique, magnetism refrigeration presents following advantages over compression refrigeration: (1) without environmental pollution, (2) high efficiency, (3) facilitating to miniaturization, (4) stabilization and reliability[19].

3.1 Principles of Magnetism Refrigeration

Magnetic refrigeration is based on the magnetocaloric effect the ability of some materials to become hot when magnetized and to cool when removed from the magnetic field [20]. The reversible change of temperature is achieved through the change of magnetization of a ferromagnetic or paramagnetic material.

The principle of refrigeration by adiabatic demagnetization is as follows: When magnetizated isothermally, magnetic work medium discharges heat into environment due to orderly magnetism matrix and decreasing magnetic entropy; while at adiabatic demagnetization, the temperature of magnetic work medium decreases because of disorderly magnetism matrix and increasing magnetic entropy[19]. Figure 3 illuminates the work mechanism of Carnot cycle refrigeration by adiabatic demagnetization.

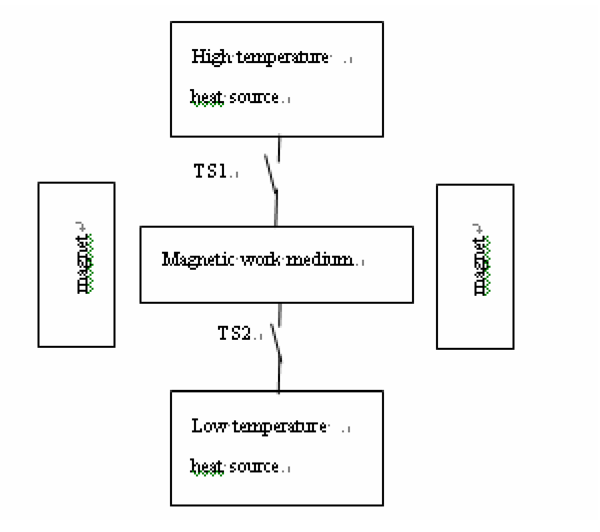

Fig. 3 Principle of Carnot magnetism refrigeration

1) During magnetization isothermally, switch TS1 is on and TS2 is off. Entropy of work medium in magnetic field decreases, heat flows from work medium to high temperature heat source.

2) During adiabatic demagnetization, both switches TS1 and TS2 are off. When magnetic field is takeoff gradually, spin of work medium becomes disorderly, energy must be consumed to decrease the temperature of work medium to that of low temperature heat source.

3) In the course of isothermal demagnetization, TS1 is on while TS2 is still off. Magnetic field decreases continuously, work medium absorbs heat from heat source.

4) In the period of adiabatic magnetization, switches TS1 and TS2 are off. Under a small magnetic field, the temperature of work medium will increase gradually to that of high temperature heat source.

3.2 Development Status of Magnetic Refrigeration Technology

According to various temperature region, magnetic refrigerators can be classified into sub-cryogenic (0K), cryogenic (less than 15K), middle temperature (15-77K), and high temperature (more than 77K).

1) Low temperature region (< 15 K): an important temperature region for liquid helium. By later 1980’, many studies about magnetic refrigeration had been conducted, which need not be said more than is needed[21].

2) Low temperature region (15～77 K): an important temperature region of liquid hydrogen. People attach wide importance to investigation of this temperature region owing liquid hydrogen’s great economical benefit. In 1983, Backley from Los Alamos invented a hydrogen liquefier of circumrotate magnetic refrigeration which can directly cooling hydrogen from room temperature to 20K[22].

3) High temperature region (higher than 77 K). Though magnetic refrigeration at room temperature has wide market latent, its application counters with many difficulties. Since the quantity of crystal lattice entropy is very large at near room temperature region, if no measures are made to discharge crystal lattice entropy, effective engropy change becomes so small that only under hundreds of Tesla magnetic field can demanded refrigerating capacity be obtained[23].

Additionally, effective heat exchange is very important for magnetic refrigeration cycle process at room temperature.

From the viewpoint of development status inside or outside country, there are great differences in refrigerating capacity and temperature span between high temperature region magnetic refrigerator and steam compressor. Main difficulties in application focus on: 1) the MCE of magnetic material is not enough large; 2) no enough magnetic field intensity; 3) Heat exchange and hold-over or cold accumulation technology. Magnetic refrigeration at room temperature will become a new and latent refrigeration manner because of its high efficiency and environment-friendly. However, only there is breakthrough in field of material science and refrigeration technology can this refrigeration technology be widely applied.

4. THERMOELECTRIC REFRIGERA- TION TECHNOLOGY

Thermoelectric (TE) refrigeration is more and more attention-getting because of initiating prohibition of CFCs in 1990s and progresses in the fields of electronics, new materials and other technologies concerned. As a result, thermoelectric refrigeration technology was limited to its applications in which reliability or convenience is more important than economy. The application progress of thermoelectric refrigeration was reviewed in the past 40 years, especially the recent advance in the past 10 years. It presents some situations or trends as follows:

1) Large-scale TE air conditioner and cooling equipment are hardly used widely in civil application field at present; however, they can be used in the military application and space-science with their special advantage.

2) TE heat-pump is practical in the area where there is abundant underground water resource and air conditioner used only to be cooling. At the same time, the application of TE air conditioner used in the cab and TE water heater can be attractive. A great variety of special uses of TE cooling facilities can’t be replaced by other cooling methods with its flexibility and compatibility.

3) Micro-Dimension TE module is an important development tendency; however, theory of structure model optimization has big room to develop in the engineering application. Super-lattice nano-material’s development will be the potential way to improve TE merit figure, at the same time, compatible TE film-shape integrated structure will be the trend of the micro-electronic cooling.

4) Since 1980s, refrigerant CFCs had been forbidden to use all over the world, following the energy crisis and sustainable problem intensive, application of TE cooling technology will face more and more development chance.

The thermoelectric effect is of very small magnitude with ordinary metals. But late in the 1950s it was found that doped semiconductors had much larger Peltier coefficients. Abram Ioffe, for the first time suggested the possibility of a thermoelectric home refrigerator using semiconductors. Virtually every known semiconductor, semi-metal and alloy was evaluated for its thermoelectric properties and Bi2Te3/Sb2Te3 alloys were found to be the best materials at room temperature. However, only moderate amount of cooling was produced with the help of some TE materials giving poor efficiencies as compared to compressor-based refrigerators[24,25].The four different approaches to the development of new superior TE materials are: i) binary and ternary covalently bonded semiconductors; ii) semiconductors with ‘*rattling*’ atoms or molecules; iii) correlated metals or semiconductors and iv) super lattices.

5. COMPARISON AMONG THERMO-ELECTRIC REFRIGERATION, MAGNETIC REFRIGERATION AND ADSORPTION REFRIGERATION

Thermoelectric, magnetic and adsorption refrigeration are all eco-friendly technologies which are received more and more attention in the day of increasing serious energy and environment problems. However, there are obvious differences in physical principle, applicability, thermodynamic and economical characteristic among these three technologies, which are listed in Table 2.3.

Table 2.3.Comparison among thermoelectric refrigeration, magnetic refrigeration and adsorption refrigeration

Refrigerating manner		Thermoelectric refrigeration	Magnetic refrigeration	Adsorption refrigeration
Work medium (Energy flow carrier)	Work medium	Electron	Magnetic material	Work medium couple
	Entropy density	Low	High	Low
Physical principle	Outfield	Electric field	Magnetic field	Pressure
	equipment	PN electric idol couple	magnet	adsorption bed
	Energy conversion	Electron transplant	Excitation, de-magnetization	Adsorption, desorption
Applicability, economical characteristic, development status	Low temperature region (< 15 K)	Inapplicable	Technically mature	Inapplicable
	Middle temperature region (15-77 K)	Difficult to applicable	Small applicable scope	inapplicable
	High temperature region(＞77 K)	Good applicability, special superiority	Applicable, Technically immature	Inapplicable
	Near room temperature region	Good applicability, special superiority	Without applicable technique and economical characteristic	Applicable, without applicable technique and economical characteristic

6. CONCLUSIONS

In conclusion, thermoelectric refrigeration possesses following advantages: longer development period; more technically mature; widest application field; larger refrigerating capacity; good economical trait when in small refrigerating capacity; in some application field, it has special superiority which can not be replaced by others; more and more importance are attached to the application of low-grade energy source and the recycle of waste heat.

Magnetic refrigeration with relative short development period has been applied in lowtemperature region due to perfect technique, while in middle temperature region, the application technique is imperfect, especially in high temperature region there is no applicable technique up till now.

Adsorption refrigeration with a short study period can be used only in the condition of near room temperature. Compared with compression refrigeration, its advantage is the utilization in the fields to which that compression refrigeration is inapplicable, such as the use of solar energy, geothermy energy, and the recycle of waste and exhaust heat. For adsorbing refrigeration, however, there are three disadvantages: technically inapplicable, cost ineffective and without competition superiority.

REFERENCES

[1] Wang Ruzhu. Study on a new solidadsorptionrefrigeration pair: active carbon fiber methanol[J]. ASME Journal of Solar Energy, 1997, 119 (3): 214-219. (In Chinese)

[2] Sakoda A, Suzuki M. Simultaneous transport of heat and adsorbate in closed type adsorption cooling system utilizing solar heat[J]. ASME Journal of Solar Energy Engineering, 1986, 108(2):239-245.

[3] Zheng W. Effect of operating conditions on the performance of two-bed closed-cycle solid-sorption heat pump systems[J]. ASME Journal of Solar Energy Engineering, 1995, 117(2): 181-186. (In Chinese)

[4] Mei ning, Li huanjun, Chu dongsheng et al. Studies of the performance and thermodynamic mechanism

of an engine exhaust-powered solid adsorption refrigerator[J]. Journal of Ocean university of Qinghai, 1996，26（2）: 212—222. (In Chinese)

[5] Zhang L Z, Wang L. Performance estimation of an adsorption cooling system for automobile waste heat recovery[J]. Applied Thermal Engineering, 1997,17(12): 1127-1139.

[6] Poyelle F, Guiileminot J J, Meunier F. Experimental tests and predictive model of an adsorption air condition unit[J]. Industry & Engineering Chemistry Research. 1999, 38(1): 298-309.

[7] Wang ruzhu, Dai wei, Zhou hengxiang et al. Study on the adsorption refrigeration performances of domestic activated carbon-methanol pairs[J]. Acta Energiae Solaris Sinica, 1995, 16(2): 55-160. (In Chinese)

[8] Talmainot T Z. adsorption refrigeration using monolithic carbon-ammonia pair[J]. International Journal of Refrigeration, 1997, 20(2): 146-155.

[9] Saha B B, Boelman E C, Kashiwaki T. Computional analysis of an advanced adsorption refrigeration cycle[J]. Energy-The International Journal, 1995, 20(10): 983-994.

[10] Erhard A, Spindler K, Hahne E. Test and simulation of a solar powered solid sorption cooling machine[J]. International Journal of Refrigeration, 1998, 21(2): 133-141.

[11] Meunier F. Performance of adsorption heat pumps: active carbon-methanol and zeolite-water pairs[J]. ASHRAE trans, 1990, 96(1): 267-274.

[12] Fuller T A, Wepfer W J, Shelton S V. A two-temperature model of the regenerative solid-vapor heat pump[J]. Journal of Energy Resources Technology, Transactions of the ASME, 1994, 116(2): 297-304.

[13] Tchernev D I. High efficiency regenerative zeolite heat pump[J]. ASHRAE Trans, 1988, 94(1): 2024-2032.

[14] Cacciola G, Cammarata G, Fichera A, et al. Advances on innovative heat exchangers in adsorption heat pumps. IN Proceedings of the Symposium:Solid Sorption Refrigeration, Paris, 1992, 221-226.

[15] Teng yi, Wang ruzhu, Wu jingyi et al. Application of spiiral plate adsorber to heat regenerative adosrption refrigeration cycles[J]. Acta Energiae Solaris Sinica, 1997, 18(3): 243-251. (In Chinese)

[16] Douss N. Experimental study of adsorption heat pump cycles[J]. International Chemical Engineering, 1993, 33(2): 207-214.

[17] Vasiliev L L, Antux A A, Kulakov,et al. Heat pipe cooled and heated solid sorption refrigerator. In Proceedings of 19th International Congress of Refrigeration, 1995. IIIa: 200-208.

[18] Fang liguo, Feng yi, Tan yingke. Theoretical and experimental research on economical work media pairs's method for environmental protection adsorption refrigeration[J]. Environment Protection Science, 1997, 23(2): 1-4. (In Chinese)

[19] Chen bangguo. New technology of low temperature Refrigeration[M]. Beijing: Mechanical Industry Press, 2004.8: P57-63. (In Chinese)

[20] Mark Alpert, A cool idea[M], Scientific American, p. 44, May 1998.

[21] Chen yuanfu, Chen yungui, Teng baohua. Develop status of magnetic regrigeration: II magnetic refrigeration technology [J].Cryogenics, 2001(2): 57-63. (In Chinese)

[22] Barclay J A. Wheel 2 type magnetic refrigerator. 1982 , U. S. Patent , 4408463

[23] Brown G V. Magnetic heat pumping near room temperature[J]. J. Appl. Phys. 1976, 47(8): 3673-3680.

[24] Mahan G, Sales B and Sharp J, Thermoelectric materials: new approach to an old problem, Physics Today, pp. 42-47, March 1997.

[25] Fink D G and Christiansen D. Electronics Engineer's HandBook (Coolers) 2nd edition[M], McGraw-Hill, USA, pp.11-85, 1986.